TUNABLE ADD/DROP NODE FOR AN OPTICAL NETWORK

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RELATED APPLICATIONS

This application is related to U.S. patent application serial number __________ entitled "Optical Filter Module Having A Selectable Bandwidth" filed on November 28, 2000 and is incorporated by reference herein in its entirety.

BACKGROUND

Field of the Invention

The invention relates in general to one or more optical networking components and, more particularly, to add/drop nodes.

Background of the Invention

Optical networks include one or more optical fibers that each carry several channels of information. Each channel of information is carried in a light signal having a different wavelength. A variety of optical networks also include one or more add/drop nodes where one or more channels of information is added to an optical fiber or dropped from an optical fiber.

Many add/drop nodes allow a first signal of a channel of information to be dropped from an optical fiber and allow another signal of the same channel to be added to the same optical fiber. Different information can be carried within the channel using the different signals. For instance, the first signal of the channel can be destined for a first city and the second signal can originate at the first city and be destined for a second city. When the add drop node is located in the first city, the first signal on the channel can be dropped from the optical fiber for processing in the first city. The second signal on the channel can be added to the fiber optic and directed to the second city by the network.

Add/drop nodes can be tunable. A tunable add/drop node allows the channel of information that is dropped and/or added at a particular add/drop node to be selected. When the add/drop nodes changes the channel that is added and/or dropped from a first channel to a second channel, the add/drop node must scan through each of the channels between the first channel and the second channel. As a result, a fiber optic carrying a channel dropped at the node would temporarily carry each of the channels between the first channel and the second channel. Hence, information carried in the channels between the first channel and the second channel can be lost as the add/drop node is tuned.

There is a need, therefore, for an add/drop node that can be tuned without loss of information.

SUMMARY OF THE INVENTION

In an exemplary embodiment of the invention, an input port of an add/drop node receives a plurality of optical channels. An add/drop port transmits a first drop channel of the plurality of channels when in a first channel mode and a second drop channel of the plurality of optical channels during a second channel mode. An output port transmits the second drop channel during the first channel mode and the first drop channel during the second channel mode. When the add/drop node is tuned from the first channel to the second channel, the output port transmits at least the plurality of channels spectrally located between the first channel and the second channel.

In one exemplary implementation, a switch directs all channels received at the input port to the output port while a tunable channel selector is tuned to the appropriate channel. The switch directs the channels from the input port to the channel selector after the channel selector is tuned. The appropriate channels are directed to and from the add/drop port by the channel selector. The channel selector can have a variable bandwidth, allowing the bandwidth of add/drop channel to be changed.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 is a block diagram of a add/drop node in accordance with an exemplary embodiment of the invention.

Figure 2 is a block diagram of a first exemplary implementation of the add/drop node in accordance with the exemplary embodiment of the invention.

Figure 3 is a block diagram of a second exemplary implementation of the add/drop node in accordance with the exemplary embodiment of the invention.

Figure 4 is a block diagram of a third exemplary implementation of the add/drop node in accordance with the exemplary embodiment of the invention.

Figure 5 is a block diagram of a fourth exemplary implementation of the add/drop node in accordance with the exemplary embodiment of the invention.

Figure 6A is a block diagram of a fifth exemplary implementation of the add/drop node in accordance with the exemplary embodiment of the invention.

Figure 6B is a block diagram of a sixth exemplary implementation of the add/drop node in accordance with the exemplary embodiment of the invention.

Figure 7 is block diagram of an exemplary drop filter module.

Figure 8 is block diagram of an exemplary add filter module.

Figure 9 is a block diagram of an exemplary channel selector implemented as a multiple drop channel selector in a transmit-through configuration.

Figure 10 is a block diagram of an exemplary channel selector implemented as a multiple drop channel selector in a reflective configuration.

Figure 11 is a block diagram of an exemplary channel selector implemented as a multiple add channel selector in a transmit-through configuration.

Figure 12 is a block diagram of an exemplary channel selector implemented as a multiple add channel selector 1200 in a reflective configuration.

Figure 13 is block diagram of an exemplary channel selector implemented as a single add/drop channel selector.

Figure 14 is a block diagram of an exemplary channel selector implemented as a multiple add/drop channel selector.

Figure 15 is block diagram of exemplary tunable filter module.

Figure 16 is a block diagram of a variable bandwidth tunable filter module in accordance with an exemplary embodiment of the invention.

Figure 17 is a graphical illustration of a optical frequency spectrum in accordance with the exemplary embodiment of the invention.

Figure 18 is flow chart in accordance of an exemplary method of managing channels at an add/drop node.

Figure 19 is a flow chart of an exemplary method of tuning a channel selector in an add/drop node.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In accordance with an exemplary embodiment of the invention, an optical add/drop node tunes from a first drop channel to a second drop channel without losing information contained within optical channels spectrally located between the two optical channels. Throughout this disclosure, the term "optical channel" refers to any band-limited frequency spectrum within the light spectrum. One or more optical signals can be conveyed through an optical channel.

A plurality of channels received at the input of the optical add/drop node are directed through one or more channel selectors to direct a drop channel to an add/drop port of the add/drop node. An alternate optical channel received at the add/drop port is directed to the output of the add/drop node in place of the drop channel. In response to a channel controller, the drop channel can be changed from a first drop channel to a second drop channel. In one implementation, the plurality of optical channels are directed from the input to the output while a channel selector is tuned to the second drop channel. In another implementation, a second channel selector is tuned to the

second drop channel prior to directing the plurality of optical channels to the second channel selector. Although several exemplary embodiments are discussed below, those skilled in the art will recognize other implementations and variations based on the teachings herein.

Figure 1 is a block diagram of an optical add/drop node 100 in accordance with an exemplary embodiment of the invention. In the exemplary embodiment, the add/drop node 100 is a wavelength add/drop node (WAD). A plurality of optical channels are received at an input port 102 of the optical add/drop node 100. During a first channel mode of operation, one or more drop channels are diverted to an add/drop port 106 allowing only the remaining plurality of channels to be transmitted at the output port 104. For example, if the plurality of channels are represented by λ_1 through λ_n, channel λ_2 may be diverted to the add/drop port 106 resulting in channels $\{(\lambda_1+\lambda_2+ \ldots \lambda_n) - \lambda_2\}$ to be produced at the output port 104.

In the exemplary embodiment, the add/drop port 106 is configured to receive at least one alternate optical channel which can be directed to the output port 104. Continuing with the example, if an alternate optical channel is represented by λ_a, the output at the output port 104 is $(\lambda_1+\lambda_a+ \ldots \lambda_n)$. Although the add/drop port 106 provides both an input to receive alternate optical channels and an output to transmit optical channels in the exemplary embodiment, the add/drop port may perform the functions of solely an input or an output. Further, the add/drop port 106 may be implemented using any number of inputs and outputs.

A channel controller 108 in communication with the add/drop node 100 directs the add/drop node 100 to select a particular add/drop channel or channels. In the exemplary embodiment, the channel controller 108 is a printed circuit board that provides all of the control interface and control signals. The channel controller 108 receives signals from a network management layer of the optical network system, and sends data to the add/drop node 100 to control the switch setting, timing setting, channel number setting, adding or dropping setting, and other settings, positions or

parameters readily recognized by those skilled in the art. If the add/drop node 100 has a tunable bandwidth allowing selection of a bandwidth, the channel controller 108 also provides control signals to adjust the bandwidth setting.

The add/drop node 100 is in the first channel mode when the first drop channel is directed to the add/drop port 106 and is in the second channel mode when the second channel is directed to the add/drop port 106. During the period between the first channel mode and the second channel mode, the optical channels between the first drop channel and the second drop channel are directed to the output port 104. In some of the exemplary implementations discussed below, all of the plurality of optical channels received at the input are directed to the output port 104 while a channel selector is tuned from a first frequency bandwidth of the first drop channel to a second frequency bandwidth of the second drop channel during a channel tuning mode. As is discussed below in further detail, a filter element within the channel selector is shifted to a different position relative to an incident optical signal beam, that includes the plurality of optical channels, to tune the channel selector. The add/drop port 106 may be configured to add or drop any number of optical channels.

Accordingly, no information conveyed by the plurality of optical channels is lost during the channel tuning mode. If the add/drop node 100 is implemented as part of an optical networking system where channels are dropped and added to the plurality of optical channels in order to route information to the intended destination, information not intended to be directed away from the output port 104 is maintained at the output port 104 during the channel tuning mode.

Figure 2 is a block diagram of a first exemplary implementation of the add/drop node 100 in accordance with the exemplary embodiment of the invention. A switch 202 is optically coupled to a channel selector 204 to the input and output ports 102, 104. Throughout this disclosure, "optically coupled" refers to an optical connection where the two or more elements, ports or devices are in optical communication. The optical connection may be a direct physical connection or may

be a connection through one or more additional devices or elements. Optical signals and channels within an optical frequency spectrum or portion of optical frequency spectrum may be transmitted between elements, devices or ports that are optically coupled.

In the first exemplary implementation of the add/drop node 100, the switch 202 includes four ports 206-212. The switch 202 may be any one of several optical switches capable of performing the functions as described herein. Examples of suitable switches are the 2 by 2 single mode fiber optic switches manufactured by the JDS Uniphase, E-Tek Dynamics and DiCon Fiberoptics Inc. companies. A first input port 206 of the switch 202 is optically coupled to the input port 102 of the add/drop node 100. The first input port 206 and the add/drop input port 102 may be the same element. A first output port 208 of the switch 202 is optically coupled to the output port 104 of the add/drop node 100. The first output port 208 may be the same element as the output port 104 of the add/drop node 100. A second output port 210 of the switch 202 is optically coupled to an input of the channel selector 204 and an output of the channel selector 204 is optically coupled to the second input port 212.

In a first position of the switch 202, optical signals and channels are directed from the first input port 206 to the first output port 208. In a second position, the optical signals and channels are directed from the first input port 206 to the second output port 210 and optical signals and channels received at the second input port 212 are directed to the first output port 208.

The channel selector 204 may have any one of various configurations as will be discussed in further detail below. For example, the channel selector 204 may be tunable and have fixed bandwidth or may be tunable and have a variable bandwidth that can be selected by the channel controller 108. The channel selector 204 diverts a portion of the incoming optical spectrum received at its input to its output coupled to the add/drop port 106 and allows the remainder of the optical spectrum received at the input to continue to the second switch input port 212. The add/drop port 106 may be

one of the outputs of the channel selector 204. Further, the add/drop port 106 may physically consist of two or more separate ports. An add port may be configured to receive alternate optical channels and a drop port may be configured to transmit the portion of the spectrum diverted from the received optical spectrum. In systems that utilize a single optic fiber, a device such as a circulator may be utilized to allow the add/drop port 106 to be bi-directional. In implementations where separate fibers are used for the add and drop ports, each of the ports facilitates transmission in only one direction.

Assuming, for example, channels λ_1 through λ_n are received at the first switch input port 206 and directed to the channel selector 204 through the second switch output port 210, a channel, such as channel λ_3, is directed to the add/drop port 106. The remainder of the optical channels $\{(\lambda_1+\lambda_2+ \ldots \lambda_n)-\lambda_3\}$ are directed to the second switch input port 212. The switch 202 directs this remainder of channels to the first switch output port 208 and, therefore, to the output port 104 of the add/drop node 100. In addition, an alternate channel (λ_a) received at the add/drop port 106 can be combined with the remainder of the optical channels to form a plurality of channels including channels $\{(\lambda_1+\lambda_2 \ldots \lambda_n) - \lambda_3 + \lambda_a\}$. The alternate channel (λ_a) has the same wavelength as the dropped channel (λ_d) and may or may not have the same bandwidth as the dropped channel (λ_d). In this example, therefore, channels λ_3 and λ_a have the same frequency.

In the first exemplary implementation of the exemplary embodiment, the channel selector 204 is tunable and responsive to commands received from the channel controller 108. When the channel controller 108 instructs the add/drop node 100 to change from a first channel to a second channel, the switch 202 is set to direct signals received at the first input port 206 to the first output port 208 allowing all of the plurality of channels received at the input port 102 to be directed to the output port 104. The channel selector 204 is tuned from the first channel to the second channel. Although the channel may scan through each of the optical channels between

the first channel and the second channel as it changes channels, all of the channels received at the input port 102 are present at the output port 104 minimizing the loss of information. After the channel selector 204 is set to the second channel, the switch 202 is configured to direct optical channels received at the second switch input port 206 to the first switch output port 208.

In the exemplary embodiment, the channel controller 108 provides the appropriate control signals to the switch 202 and channel selector 204 to perform the functions described above. The data protocol of the optical network system defines the transmission traffic direction, switch states (positions), and frequencies of the channels to be added and /or dropped. Using known techniques, the channel controller 108 converts the incoming digital data into the appropriate voltage or current drive level to set the switch 202 to the appropriate position, and to tune the channel selector 204 to the first channel mode or the second channel mode.

Figure 3 is a block diagram of a second exemplary implementation of the add/drop node 100 in accordance with the exemplary embodiment of the invention. In the second exemplary implementation, the add/drop node 100 includes at least a switch 302, an optical channel combiner 306, and a channel selector 204. An input 308 of the switch 302 is optically coupled to the input port 102 and may be the same element as the input port 102. The first output 310 of the switch 302 is optically coupled to a first combiner input 312 of the optical channel combiner 306. A second output 314 of the switch 302 is optically coupled to an input of the channel selector 204. The output of the channel selector 204 is optically coupled to a second combiner input 316 of the optical channel combiner 306.

The switch 302 may be any one of several optical switches capable of performing the switch functions described below. As those skilled in the art will recognize, the switch 302 should have sufficiently high isolation in order to avoid cross talk and possible interference. An examples of suitable switches include 1 by 2 single mode optical switches manufactured by the JDS Uniphase, E-Tek Dynamics,

Oplink Communications, Inc., PIRI (Photonic Integration Research, Inc.) and DiCon Fiberoptics Inc. companies. In a first position of the switch 302, the plurality of optical channels received at the input 308 are directed to the first output 310. In a second position, the plurality of optical channels are directed to the second output 314.

The optical channel combiner 306 combines optical channels received at the first input 308 and the second input 316 to produce a combined optical spectrum of resulting optical channels at the output 318 of the optical channel combiner 306. The optical channel combiner 306 may be any one of several optical channel combiners capable of performing the combining functions described below. Examples of suitable optical channel combiners include 2 by 1 optical signal combiners manufactured by the JDS Uniphase, E-Tek Dynamics, Oplink Communications, and DiCon Fiberoptics Inc. companies.

When the switch 302 is in the first position, all of the plurality of optical channels received at the input 102 are directed to the first input 312 of the optical channel combiner 306 and none of the optical channels are directed to the channel selector 204. Accordingly, if no alternate optical channel is added by the channel selector 204, no channels will be present at the second combiner input 316 and only the plurality of optical channels received at the input 102 will be produced at the combiner output 318. If an alternate optical channel is received at the add/drop port 106, the alternate optical channel will be combined with the plurality of optical channels and will interfere with the optical channel having the same frequency as the alternate optical channel. This interference can be avoided by regulating the add/drop port 106 to the channel selector 204. Further, the interference will not be an issue since most networking protocols require a channel to be dropped before a channel is added. Also, if the add/drop node 100 is utilized only as a drop node, where no alternate channels are received at the add/drop port 106, interference is not an issue.

When the switch 302 is in the second position, the plurality of optical channels are directed to the second output 314 of the switch 302 and the input of the channel selector 204. During the first channel mode, the channel selector 204 diverts the first optical channel to the add/drop port 106 and directs any alternate optical channel to the second input 316 of the optical channel combiner 306. The optical channel combiner 306 combines the optical channels received at both combiner inputs 312, 316 to produce an output optical frequency spectrum. The output optical frequency spectrum includes the plurality of optical channels received at the input port 102 without the first optical channel and the alternate optical channel.

In response to the channel controller 108, the channels are changed from the first channel to the second channel. Before the channel selector 204 begins changing channels during the channel tuning mode, the switch 302 is set to direct all of the plurality of optical channels from the input 308 to the output 310. As explained above, all of the plurality of channels appear at the output 104 of the add/drop node 100 during the channel tuning mode when the switch 302 is in this first position.

During the channel tuning mode, the switch 302 remains in the first position and the channel selector 204 changes from the first channel to the second channel in response to the channel controller 108. After the second channel is selected, the switch 302 is set to the second channel mode allowing the plurality of optical channels received at the input 102 to pass through the channel selector 204. During the second channel mode, the second optical channel of the plurality of optical channels is dropped by directing the second optical channel to the add/drop port 106. The output frequency spectrum produced at the output 104, therefore, includes plurality of optical signals received at the input port 102 where the second optical channel is replaced with the alternate channel at the same frequency.

Figure 4 is a block diagram of a third exemplary implementation of the add/drop node 100 in accordance with the exemplary embodiment of the invention. The third exemplary implementation is the same as the second exemplary

implementation described above in reference to Figure 3 except that the combiner 306 is a switch 402. As those skilled in the art will recognize, the isolation requirements of the switch 302 can be relaxed by using a second switch 402. Examples of a suitable switches for use as the first switch 302 and the second switch 402 include 1 by 2 single mode optical switches manufactured by the JDS Uniphase, E-Tek Dynamics, Oplink Communications, Inc., PIRI (Photonic Integration Research, Inc.) and DiCon Fiberoptics Inc. companies.

The operation of the add/drop node 100 in the third exemplary implementation is similar to the second exemplary implementation except that the position of the second switch 402 is changed simultaneously with the position of the first switch 302. When the first switch 302 is in the first position and allows the plurality of optical channels at the input port 102 to pass directly to the first input 404 of the second switch 402, the second switch 402 is also in a first position that allows the optical channels at only the first input 404 to pass to the output 406. When the first switch 302 is in the second position the plurality of optical channels are directed through the channel selector 204 and the resulting optical channels at the output of the channel selector 204 are received at the second input 408 of the second switch 402 which also in a second position. Only the optical channels received at the second input 408 of the second switch 402 are directed to the output 104 when the second switch 402 is in the second position.

Therefore, during the channel tuning mode, the switches remain in the first position allowing all of the channels received at the input 102 to pass to the output 104. After the channel selector 204 is tuned to the appropriate channel, the switches 302, 402 are set to the second position.

Figure 5 is a block diagram of a fourth exemplary implementation of the add/drop node 100 in accordance with the exemplary embodiment of the invention. In the fourth exemplary implementation, the add/drop node 100 includes two 1 by 2 optical switches 502, 504, two channel selectors 506, 508 and an optical combiner

510. During the first channel mode, the first switch 502 is in a first position and the plurality of optical channels received at the input 102 are directed to the first channel selector 506. The first channel selector 506 directs the first drop channel to the optical combiner 510 and the remainder of the plurality of optical channels to the second switch 504. The second switch 504 is also in a first position during the first channel mode and directs signals at the first input port 512 to the output port 104.

During the second channel mode, the second switch 502 is in a second position and the plurality of optical channels are directed to the second channel selector 508. The second channel selector 508 directs the second drop channel to the optical channel combiner 510. The second switch 504 is in the second position during the second channel mode and directs the optical channel at the second input port 514 to the output 104.

Although one or both of the channel selectors 508 may be fixed, both channel selectors are tunable in the fourth exemplary implementation. When the drop channel is changed from the first drop channel to the second drop channel, the second channel selector 508 is tuned to the second drop channel. During this channel tuning process, both of the switches 502, 504 remain in the first position. The switches 502, 504 are simultaneously changed from the first position to the second position after the second channel selector 508 is tuned to the second drop channel.

The channel combiner 510 combines the outputs from both of the channel selectors 506, 508. An optical signal will only be present at the output of one of the two channel selectors 506, 508 at any one time and, therefore, only one of the drop channels will be directed to the add/drop port 106. Examples of suitable optical channel combiners include 2 by 2, 3dB optical channel combiners manufactured by the JDS Uniphase, E-Tek Dynamics, Oplink Communications, Inc., PIRI (Photonic Integration Research, Inc.) and DiCon Fiberoptics Inc. companies.

An alternate channel received by the add/drop port 106 is directed to both channel selectors 506, 508 through the optical channel combiner 510. Those skilled in

the art will recognize that the amplification of the alternate channel may be necessary to maintain a suitable signal to noise ratio at each channel selector 508. Alternatively, a switch can be substituted for the channel combiner 510.

If at least one of the channel selectors 506, 508 is not capable of directing all of the plurality of signals from the input port 102 to the output port 104, it may be desirable to utilize 1 by 3 switches where one of the output ports of the first switch 502 is directly connected to one of the input ports of the second switch 504. Such a modification allows the add/drop node 100 to pass the plurality of optical channels received at the input port 102 to the output port 104 which may be necessary in some optical networking schemes.

Figure 6A is a block diagram of a fifth exemplary implementation of the add/drop node 100 in accordance with the exemplary embodiment of the invention. In the fifth exemplary implementation, the add/drop node 100 includes two switches 602, 604, and a plurality of channel selectors 606-610. The first switch 602 is a 1 by N switch that has a single input port 612 and N output ports 614-620. The second switch 604 has a plurality of input ports 622-628 and an output port 630. Optical channels received at the input port 612 of the first switch 602 can be directed to any one of the output ports 614-620. Any one of the input ports 622-628 of the second switch 604 can be directed to an output port 630 of the second switch 604 and the output port 104 of the add/drop node 100. The positions of the two switches 602, 604 are changed simultaneously to allow selecting a particular channel selector (606-610).

In the fifth exemplary implementation of the add/drop node 100, each channel selector 606-610 is tunable to select a particular add/drop channel and may have either a unique fixed bandwidth or variable selectable bandwidth. Therefore, depending on system requirements, the fifth exemplary implementations of the add/drop node 100 may include any number or combination of fixed bandwidth channel selectors having a fixed frequency, frequency tunable channel selectors

having a fixed bandwidth, frequency tunable channel selectors having a selectable bandwidth, and fixed frequency channel selectors having selectable bandwidth.

The channel controller 108 provides the necessary control signals to adjust the bandwidth and frequency of each channel selector 606-610. Therefore, multiple control connections may be required between the channel controller 108 and the add/drop node 100. As explained above, the channel controller 108 can be implemented as a separate printed circuit board that provides all of the control interface and control signals. In addition to receiving the other channel information , the channel controller 108 receives the information bandwidth setting. The data protocol will define the transmission traffic direction, the switch positions, the channels being added/dropped and the bandwidth requirement which depends on the modulated data rate required by the standards such as OC-12, OC-48 and OC 192. If the filter module with the channel selector is a frequency tunable filter module having a selectable bandwidth, the controller provides appropriate signals the adjustment mechanism to set the filter module as discussed below.

When the switch positions are set such that the plurality of channels received at the input 102 are directed through the first channel selector 606, a drop channel having frequency bandwidth of BW_1 is dropped while an alternate optical channel having the same bandwidth can be added to the plurality of optical channels as directed to the output port 104. By changing the position of the switches 602, 604 to allow the plurality of optical channels to pass through the second channel selector 608, a second frequency bandwidth can be selected. Since the channel selectors 608 are tunable in the fifth exemplary implementation of the add/drop node 100, the frequency of the drop channel can be the same as the drop channel when the first channel selector 606 is selected or may be different.

In other implementations, the second switch 604 can be replaced with an optical channel combiner. Utilizing an optical channel combiner for the second switch

604, requires that the first switch 602 have adequate isolation between the ports in order to avoid cross talk.

Figure 6B is a block diagram of a sixth exemplary implementation of the add/drop node 100 in accordance with the exemplary embodiment of the invention. In the sixth exemplary implementation, a single N by N switch 601 directs the plurality of optical channels received at the input 102 through the plurality of channel selectors 606-610. The signals received at the first input port 630 can be directed to any one of the plurality of output ports 638-644 and signals on any one of the other input ports 632-636 can be directed to the first output port 638. Since each channel selector 606-610 has a unique frequency bandwidth, the bandwidth of the drop channel and the add channel can be selected by appropriately setting the switch 601.

The channel controller 108 provides commands to the switch 601 to facilitate the appropriate setting of the switch 601. The channel controller 108 further provides control signals to one or more of the channel selectors 204 that are tunable either in frequency, bandwidth or both.

The switch 601 may be an integrated N by N switch or may be an arrangement of discrete switches. Examples of suitable switches include N by N switches manufactured by the JDS Uniphase, and DiCon Fiberoptics Inc. companies.

The channel selectors 204, 506, 508, 606-610 may be implemented in a variety of ways and may have any one of several structures or configurations. Examples of some of the various suitable implementations of the channel selector 204 are illustrated in Figures 7 through 14. Each of the examples illustrated in Figures 7 through 14 is implemented using one or more filter modules. Figure 15 and 16 are block diagrams of exemplary implementations of filter modules. Accordingly, each of the filter modules used in the various channel selectors 204, 506, 508, 606-610 may be a fixed bandwidth filter module having a fixed frequency, a frequency tunable filter module having a fixed bandwidth, a frequency tunable filter module having a selectable bandwidth, or a fixed frequency filter module having selectable bandwidth.

Those skilled in the art will recognize other channel selectors and filter modules that can be used in accordance with invention. The tunable filter modules and channel selectors are controlled by the channel controller 108.

Figure 7 is a block diagram of an exemplary drop filter module 700. One or more optical channels (λ_p) are received at an input port 702. A drop channel (λ_d) is directed to the drop port 704 while the remainder of the optical channels (λ_p-λ_d) are transmitted to the output port 706.

Figure 8 is a block diagram of an exemplary add filter module 800. One or more optical channels (λ_p) are received at an input port 802. An add channel (λ_a) is directed to the add port 804 which is combined with the optical channels (λ_p) to produce a resulting spectrum ($\lambda_p + \lambda_a$) at the output port 806.

The drop filter module 700 and the add filter module 800 may be formed using a variety of structures and techniques. Examples of suitable methods of implementing the these modules 700, 800 include using techniques that utilize fiber Bragg gratings or other reflection filters, film interference filters, Mach-Zehnder filters, and birefringent filters.

The channel selector 204 may be implemented using a single drop filter module 700 and/or add filter module 800. As discussed below in reference to Figures 9 through 14, these filter modules 700, 800 can be combined in a variety of ways to form multiple add/drop channel selectors. Further, the channel selector 204 may include any number of fixed and tunable, add filter modules 800 and drop filter modules 700.

Figure 9 is a block diagram of an exemplary channel selector 204 implemented as a multiple drop channel selector 900 in a transmit-through configuration. Several drop filter modules are optically coupled in series such that multiple channels (λ_1, $\lambda_{2,}$ λ_n) are dropped. The multiple drop channel selector 900 is shown as a generic N drop channel selector 900 in order to illustrate that any number of drop filter modules can be connected to form the multiple drop channel selector

900. Each drop filter module 700 drops a particular drop channel and passes the remainder of the optical channels to the next drop filter module 700.

Figure 10 is a block diagram of an exemplary channel selector 204 implemented as a multiple drop channel selector 900 in a reflective configuration. Several drop filter modules are optically coupled such that multiple channels (λ_1, $\lambda_{2,}$ λ_n) are dropped. The multiple drop channel selector 1000 is shown as a generic N drop channel selector 900 in order to illustrate that any number of drop filter modules can be connected to form the multiple drop channel selector 900. Each drop filter module 700 drops a particular drop channel and reflects the remainder of the optical channels to the next drop filter module 700.

Figure 11 is a block diagram of an exemplary channel selector 204 implemented as a multiple add channel selector 1100 in a transmit-through configuration. Several add filter modules 800 are optically coupled in series such that multiple channels (λ_1, $\lambda_{2,}$ λ_n) are added to the plurality of optical channels (λ_p). The multiple add channel selector 1100 is shown as a generic N add channel selector 1100 in order to illustrate that any number of add filter modules 800 can be connected to form the multiple add channel selector 1100. Each add filter module 800 adds a particular add channel to the optical channels received at its input and passes the resulting combined signal to the next add filter module 800.

Figure 12 is a block diagram of an exemplary channel selector 204, 506, 508, 606-610 implemented as a multiple add channel selector 1200 in a reflective configuration. Several add filter modules 800 are optically coupled such that multiple channels (λ_1, $\lambda_{2,}$ λ_n) are added to the plurality of optical channels (λ_p). The multiple add channel selector 1200 is shown as a generic N add channel selector 1200 in order to illustrate that any number of add filter modules 800 can be connected to form the multiple add channel selector 1200. Each add filter module 800 reflects the optical channels received at its input and passes a particular add channel to its output. The resulting combined signal is directed to the next add filter module 800.

Figure 13 is a block diagram of an exemplary channel selector 204 implemented as a single add/drop channel selector 1300. A single drop filter module 700 is optically coupled to a single add filter module 800 such that a drop channel (λ_d) is dropped from and an add channel (λ_a) is added to the plurality of optical channels (λ_p).

Figure 14 is a block diagram of an exemplary channel selector 204 implemented as a multiple add/drop channel selector 1400. Several drop filter modules 700 are optically coupled to several add filter modules 800 such that multiple add channels ($\lambda_{a1}, \lambda_{a2,} \ldots \lambda_{an}$) are added to the plurality of optical channels (λ_p) and multiple drop channels ($\lambda_{d1}, \lambda_{d2,} \ldots \lambda_{dn}$) are dropped from the plurality of optical channels (λ_p). The multiple add/drop channel selector 1400 is shown as a generic N add/drop channel selector 1400 in order to illustrate that any number of drop filter modules 700 and add filter modules 800 can be connected to form the multiple add/drop channel selector 1400. Each drop filter module 700 drops a particular drop channel and reflects the remainder of the optical channels to an add filter module 700. Each add filter module 800 reflects the optical channels received at its input and passes a particular add channel received at its input to its output. The resulting combined signal is directed to the next drop filter module 700.

Figure 15 is a block diagram of exemplary tunable filter module 1500. Block 1502 illustrates a first position filter element of the tunable filter module 1500 relative to an incident light beam comprising a plurality of optical channels (λ_p). A drop channel (λ_d) is dropped from the optical channels (λ_p) and directed to a drop port while the remainder optical channels (λ_p - λ_d) are reflected to the output of the tunable filter module 1500. When the filter element is moved to second position 1504 (illustrated with a dashed line) relative to the incident light beam 1506, a second drop channel (λ'_d) is dropped. Therefore, by moving the filter element relative to the light incident beam, the filter module can be tuned to the desired drop channel (λ_d). Those skilled in the art will readily apply the concepts discussed in regard to the tunable

drop filter modules to other types of filter modules. An example of a suitable tunable filter is the tunable filter available from the Santec Corporation which is implemented using a multi-layer dielectric filter with a variable thickness using a sliding mechanism for tuning.

Figure 16 is a block diagram of a variable bandwidth tunable filter module 1600 in accordance with an exemplary embodiment of the invention. In the exemplary embodiment, the variable bandwidth tunable filter module 1600 includes a plurality of filter elements 1602-1606 where each filter element 1602-1606 has a unique bandwidth. A first filter element 1604 has first bandwidth (BW_1) and a second filter element 1606 has a second bandwidth (BW_2). The plurality of filter elements 1602-1606 are arranged such that all filter elements 1602-1606 move in conjunction with each of the other filter elements 1602-1606. For example, the plurality of filter elements 1602-1606 can be formed from a single substrate where each filter element is formed to have the desired optical characteristics. Another example includes separately forming each filter element 1602-1606 and bonding the filter elements 1602-1606 together to form the variable bandwidth tunable filter module 1600.

An adjustment mechanism 1614 facilitates moving the plurality of filter elements relative to the optical signal 1616. The adjustment mechanism 1614 is shown as a block connected to the plurality of filter elements with a dashed line to illustrate that the adjustment mechanism 1614 may be implemented in a variety of ways, of which some may not involve a direct connection between plurality of filter elements at the adjustment mechanism 1614. For example, the adjustment mechanism 1614 may be connected to the source of the optical signal (not shown) such a lens or reflector and the plurality of filter elements 1602-1606 may remain in a fixed position. Further, the adjustment mechanism 1614 may be connected to both the plurality of filter elements 1602-1606 and the source of the optical signal. The adjustment mechanism 1614 may be implemented using two separate adjustment mechanisms where each of the two facilitates position adjustment in only of the

directions 1610, 1612. In the exemplary embodiment, the adjustment mechanism 1614 moves the plurality of filter elements 1602-1606 relative to the optical signal in response to the channel controller 108 in first axis 1610 and second axis 1612. Changing the relative position of the plurality of filter elements 1602-1606 to the optical signal 1616 in the first axis 1610 allows the filter module 1600 to be tuned in frequency. Changing the relative position of the plurality of filter elements 1602-1606 to the optical signal 1616 in the second axis 1612 allows the bandwidth to be adjusted. The plurality of filter elements 1602-1606 are illustrated using dashed lines to when the plurality of filter elements 1602-1606 are moved to a second position 1618.

When the plurality of filter elements 1602-1606 are in the first position 1617, the optical signal 1616 containing the plurality of optical channels (λ_p) is received and processed to form the first drop channel (λ_{d1}) that has a first frequency and first bandwidth (BW_1). After the relative positions are changed by the adjustment mechanism 1614 such that the plurality of filter elements 1602-1606 are in the second position 1618, the second dropped channel (λ_{d2}) having a second bandwidth (BW_2) is directed to the add/drop port of the filter module 1600. Therefore, by adjusting the relative position between the plurality of filter elements 1602-1606 and the light beam received at the input port 102, the frequency and bandwidth of the add or drop channel can be selected.

Figure 17 is a graphical illustration of an optical frequency spectrum 1700 in accordance with the exemplary embodiment of the invention. A plurality of exemplary optical channels are graphically represented as trace of intensity (I) as a function of an inverse of wavelength $1/\lambda$ (or frequency). The first optical channel 1702 has a channel frequency bandwidth 1710 of BW_1 while the second optical channel 1704 has a channel frequency bandwidth 1712 of BW_2. By passing a first channel 1702 through a channel selector 204 having a filter bandwidth 1714 of BW_1, all of the channel is captured without introducing noise and degrading the signal to

noise ratio of the first channel 1702. If a filter bandwidth 1716 of channel selector 204 having a wider frequency response is used to filter the first the channel 1702, undesired signals and noise are passed along with the first channel.

By selecting a channel selector 204 having a filter bandwidth 1716 of BW_2 to add or drop the second channel 1704 allows all of the second channel 1704 to pass. Using a channel selector 204 filter bandwidth 1714 of BW_1 would result in a loss of information.

Figure 18 is a flow chart in accordance of an exemplary method of managing channels at an add/drop node 100. At step 1802, a plurality of optical channels are received at the input port 102 of the add/drop node 100. The plurality of optical channels include at least a first drop channel and a second drop channel.

Steps 1804 and 1806 are performed during the first channel mode. At step 1804, the first drop channel is directed to the add/drop port 106 of the add/drop node 100 during the first channel mode. At step 1806, the first alternate channel is directed to the output port 104 of the add/drop node 100.

At step 1808, the channel selector 204 is tuned to the second drop channel. During this channel tuning mode, one or more optical channels of the plurality of optical channels spectrally located between the first channel and the second channel are directed to the output port 104 of the add/drop node 100. In one exemplary implementation, all of the channels received at the input port 102 are directed to the output port 104 during the channel tuning mode.

Step 1810 and 1812 are performed during the second channel mode. At step 1810, the second channel is directed to the add/drop port 106 during the second channel mode. The first drop channel is directed to the output port 104 during the second at step 1812.

Figure 19 is a flow chart of an exemplary method of tuning the channel selector 204 in a add/drop node 100. At step 1902, a light beam is received.

At step 1904, a bandwidth of an optical transfer function of the variable bandwidth filter module 1600 is selected. In one implementation of the exemplary embodiment, step 1904 includes step 1906 through step 1910.

At step 1906, the first channel is diverted to the add/drop port 106 and at least the second channel is diverted to the output port 104 when the first filter bandwidth is selected.

At step 1908, a relative position between the light beam and the variable bandwidth filter module 1600 is adjusted. In response to the channel controller 108, the adjustment mechanism 1614 adjusts the relative position between the light beam and the variable bandwidth filter module 1600 such that the bandwidth of the optical transfer function of the module 1600 is selected to be substantially the same as a channel to dropped or added to the light beam. The light beam includes at least a first channel having a first channel frequency bandwidth and a second channel having a second channel frequency bandwidth. The variable bandwidth filter module includes a plurality of filter elements where each element has an optical transfer function with a unique bandwidth. The appropriate bandwidth is selected by adjusting the relative position of the variable filter module such that a filter element with the desired bandwidth receives the light beam.

At step 1910, the second channel is diverted to the add/drop port 106 and at least the first channel is diverted to the output port 104 when the second filter bandwidth is selected.

Other embodiments, combinations and modifications of this invention will occur readily to those of ordinary skill in the art in view of these teachings. Therefore, this invention is to be limited only by the following claims, which include all such embodiments and modifications when viewed in conjunction with the above specification and accompanying drawings.

WHAT IS CLAIMED IS: